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Daniel Kleppner

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Massachusetts Institute of
Technology
77 Massachusetts Avenue
Cambridge, MA 02139-4301

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
One Liberty Center
875 North Randolph Street,
Suite 1425
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14. ABSTRACT

An attempt to develop a new technique for cooling atomic hydrogen to use as an optical frequency standard is described. The technique was centered on buffer gas cooling. It was discovered that buffer gas cooling of single bohr magneton species is not feasible. The goal was then extended to studying low temperature collisional properties of several atom having large magnetic moments and anisotropic inner shells, including nickel and dysprosium, in order to determine their suitability for buffer gas cooling for

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The goal of this research was to develop a new approach for creating ultracold atomic hydrogen for metrological and other purposes, including application to an optical frequency standard based on the 1S-2S two-photon transition. The proposal grew out of experience acquired in the achievement of Bose-Einstein condensation (BEC) in hydrogen. The goals involved developing a technique to accelerate the evaporative cooling rate in hydrogen, improving the general production rate of ultracold hydrogen, and developing an experimental configuration well suited to high precision optical spectroscopy.

Our approach was based on buffer gas cooling, in which hydrogen is initially cooled by collisions with a ^{3}He buffer gas to a temperature in the range of 200-300 mK, in the center of a magnetic quadrupole trap. The gas would be pumped from the cell, and the hydrogen then cooled evaporatively, following procedures developed for achieving BEC in hydrogen. An important improvement was the proposal to trap lithium along with the hydrogen. The H-Li collision cross section is more than 1000 times larger than the H-H cross section. Thus the lithium would serve as a thermalizing agent, significantly accelerating the evaporation process.

The buffer gas cooling method had been successfully demonstrated with a variety of atoms, but all with magnetic moments larger than one μ_b (bohr magneton). On the basis of extensive modeling of the experiment, we believed that both lithium and hydrogen could be trapped and evaporatively cooled. We demonstrated trapping of lithium, but we could not thermally isolate it from the walls of the cell, a prerequisite for evaporative cooling. A detailed account of this research is given in the thesis of Nathan Brahms, listed below. Our reluctant conclusion is that the buffer gas cooling method is not useful for one bohr-magneton species.

Because our apparatus was well suited to studying atoms with magnetic moments of two or more bohr magnetons, we undertook the study of atoms in which the unpaired electrons were shielded by filled outer electron shells. Because of the anisotropic nature of the charge distribution, the question of whether the atoms reorient in collisions with a rare gas is not straightforward. We could carry out measurements at temperatures so low that there is a reasonable chance to compare the results with theoretical predictions. A secondary goal of the research was to determine whether these exotic atoms were promising for evaporative cooling into the micro-kelvin regime.

We carried out studies with nickel and dysprosium. In nickel we found the angular-momentum-changing collisions are suppressed in collisions with ^{3}He, but the degree of suppression is low compared to that in the rare-earth-metal elements. Our observations are consistent with a hypothesis of reduced collisional angular momentum transfer due to screening of the valence electrons by closed electron shells.

The spin relaxation rates in dysprosium-dysprosium collisions at low temperatures are greater than expected for the magnetic dipole-dipole interaction, suggesting that another mechanism, such as the anisotropic electrostatic interaction is responsible.

Details of the experiments and their theoretical interpretation are presented in the following publications.

Publications

Zeeman relaxation of cold atomic iron and nickel in collisions with ^{3}He. Cort Johnson, Bonna Newman, Nathan Brahms, John M. Doyle, Daniel Kleppner, and Thomas J. Greytak, Phys. Rev. **A 81**, 062706 (2010)

Magnetic relaxation in dysprosium-dysprosium collisions. Bonna K. Newman, Nathan Brahms, Yat Shan Au, Cort Johnson, Colin B. Connolly, John M. Doyle, Daniel Kleppner, and Thomas J. Greytak Phys. Rev. A, accepted for publication.

Ph.D. Theses awarded

Nathan Brahms, *Buffer gas trapping of one Bohr Magneton Species*, Ph. D. Thesis, Harvard University, 2008.

Cort Johnson, *Zeeman relaxation of cold iron and nickel in collisions with ^{3}He*, Ph. D. Thesis, Massachusetts Institute of Technology, 2008.

Bonna K. Newman, *Trapped atom collisions and evaporative cooling of non-S state atoms*, Ph. D. Thesis, Massachusetts Institute of Technology, 2008.